



RESEARCH DEPARTMENT



REPORT

Perceptible levels of audio-frequency tones in the presence of programme

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PERCEPTIBLE LEVELS OF AUDIO-FREQUENCY TONES IN THE PRESENCE OF PROGRAMME

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Summary

This Report describes subjective tests that were performed to assess the level of an interrupted tone, as a function of frequency, that would cause 'perceptible' and 'just perceptible' interference when added to programme signals. Results are given both for tests conducted entirely at baseband frequencies, using a high-quality monitoring loudspeaker, and for tests using amplitude- or frequency-modulated signals reproduced either by a stereo tuner with a high-quality loudspeaker or by battery-portable receivers.

Tests so far have used only a small selection of receivers but tentative recommendations are made for the maximum levels at which such tones could be added to programmes broadcast from a.m. and f.m. transmitters.

Issued under the authority of



Head of Research Department

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PERCEPTIBLE LEVELS OF AUDIO-FREQUENCY TONES IN THE PRESENCE OF PROGRAMME

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1. Introduction

Consideration is being given to the possibility of adding data signals subliminally to a.m. and f.m. broadcast transmissions. Various methods by which this may be done have been summarised.¹ One method, which has the advantage of being the same for both a.m. and f.m. broadcasts, is to add the data to the broadcast programme signal at a level low enough for it to be subliminal relative to normal programme volume. The experiments described in this Report were performed to decide what that level should be.

2. Method of test

2.1. General

The form of the data signals has not yet been decided but it was considered that the most stringent form would be represented by using interrupted tones at various frequencies. It was also considered that the most stringent conditions would occur during the syllabic pauses of a speech programme. Accordingly the arrangement shown in Fig. 1 was adopted for adding the tone to the programme. The tone was interrupted for one second at two-second intervals but, in order to remove switching transients, the interrupted tone was fed through a tunable bandpass filter, tuned to the frequency of the tone being used and having the frequency response shown in Fig. 2. It may readily be shown that the amplitude of each tone-burst at the output of such a filter increases exponentially, reaching α times its steady-state value after n cycles of the tone burst where

$$n = (Q/\pi) \log_e 1/(1 - \alpha)$$

where Q is the ratio of the centre-frequency of the filter to its 3 dB bandwidth. For the filter shown in Fig. 2, the

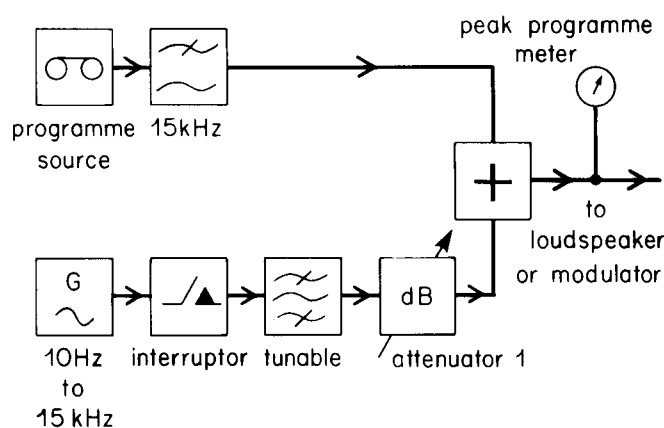


Fig. 1 - Addition of tone to programme

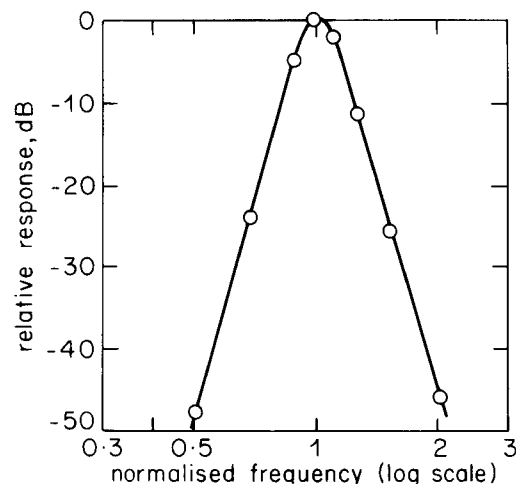


Fig. 2 - Frequency response of tunable bandpass filter

value of Q was about 10. Thus the amplitude of each tone burst increased to about 90% of its steady-state value during the first seven cycles of each burst, independently of the frequency of the tone.

The programme comprised a passage with normal syllabic pauses read by a selection of announcers (male and female). Subjective tests were performed first at baseband frequencies and, later, with the combined programme-plus-interrupted-tone amplitude-modulating or frequency-modulating a carrier and received on a selection of receivers.

All the tests were performed in a quiet listening room about 7 m x 4 m x 3 m high.

2.2. Tests at baseband frequencies

For the tests at baseband frequencies, the combined programme-plus-interrupted-tone (see Fig. 1) was fed directly to a high-quality monitoring loudspeaker type LS5/5A. Five experienced listeners took part in the tests, each of whom in turn sat, first, symmetrically in front of the loudspeaker and spaced 1.5 m from it and, second, near to one wall of the room and about 3.6 m (diagonally) from the loudspeaker. These two positions (described as Position 1 and Position 2 respectively) were chosen in order to assess the degree to which acoustic standing-wave patterns in the room may have affected the results. At each sitting position, each listener was able to move his head in order to obtain the most stringent result.

In accordance with standard practice, peak programme level was taken to correspond to a reading of 6 on the peak programme meter (p.p.m.) shown in Fig. 1 and the level of the speech programme was set to peak to 5. The level of the interrupted tone was set so that, when attenuator 1 (see Fig. 1) was set to 0 dB, the presence of the tone caused

the p.p.m. to read 6 in the absence of programme. Thus the level of the speech programme was set so as peak to 4 dB below peak programme level and the setting of attenuator 1 indicated the level of the interrupted tone relative to peak programme level.

Each listener in turn set the loudspeaker volume as required (in the absence of the interrupted tone) and then, with the interrupted tone set to a chosen frequency, was asked to adjust attenuator 1 until he judged the level of the interrupted tone to be, first, 'just perceptible' and, then, 'perceptible but not disturbing'. The settings of attenuator 1 were noted in each case.

The spread of results between all five listeners was small when the frequency of the interrupted tone was 2 kHz or less but, at frequencies of 10 kHz or above, the two younger listeners (22 – 25 years) gave results which were similar to each other but very much more demanding than those of the other three. The results are therefore presented as the average of five listeners for frequencies of 2 kHz or less, and as the average of two listeners for frequencies of 10 kHz or more.

These average results are given, for the two positions in the listening room, in Table 1.

Table 1 shows that the differences were small and evenly scattered between the individual results at the two listening positions as a function of frequency, with no obvious trends over particular ranges of frequency and, in particular, very small indeed when averaged over all fre-

quencies. The result at each frequency was therefore taken to be the average for the two positions and this is plotted as a function of frequency in Fig. 3. For comparison purposes, the normal equal-loudness contour² is also shown* in Fig. 3, adjusted in absolute level to agree with the subjective result for 'just perceptible' at 1 kHz. Agreement is reasonably good at all other frequencies, particularly at those below 1 kHz.

2.3. Tests using modulated carriers

2.3.1. Speech programme

Tests similar to those described in Section 2.2 were performed for which the programme-plus-interrupted-tone (see Fig. 1) was used either to amplitude-modulate or frequency-modulate a carrier which was subsequently reproduced from a suitable receiver. The tests involving frequency-modulation were monophonic using 50 μ s pre-emphasis in accordance with standard UK broadcast procedure. Since the speech programme had been limited before recording, no further limiter was required for either type of modulation. Peak programme level (i.e. p.p.m. reading 6) was set to produce 90% modulation depth when using amplitude modulation, or ± 34.5 kHz deviation**

* This is for a frontally-incident free field. The correction for a diffuse field of equal loudness³ is considered negligible in the present context.

** i.e. 90% of ± 38.4 kHz, the normal peak deviation of monophonic programme.

TABLE 1

Perceptibility of added tone as a function of position in room

Frequency of tone	Levels of interrupted tone, [†] dB relative to peak programme volume, for subjective grading			
	'Just perceptible'		'Perceptible'	
	Position 1	Position 2	Position 1	Position 2
10 Hz	>0	>0	>0	>0
20 Hz	-9.8	-8.2	-5.4	-5.8
30 Hz	-15.0	-14.4	-11.8	-11.4
40 Hz	-25.2	-25.4	-20.2	-20.6
50 Hz	-38.6	-41.0	-34.8	-36.4
100 Hz	-48.6	-47.6	-43.4	-43.6
200 Hz	-49.8	-52.8	-45.6	-47.6
1 kHz	-69.6	-70.4	-61.0	-65.4
2 kHz	-70.8	-67.8	-66.6	-62.2
10 kHz	-70.5	-74.0	-66.5	-65.5
12 kHz	-72.5	-69.5	-65.0	-60.5
14 kHz	-68.5	-64.5	-65.0	-59.5
Average for all frequencies	-44.9	-44.6	-40.4	-39.9

[†] Average levels for either 2 or 5 listeners, see text.

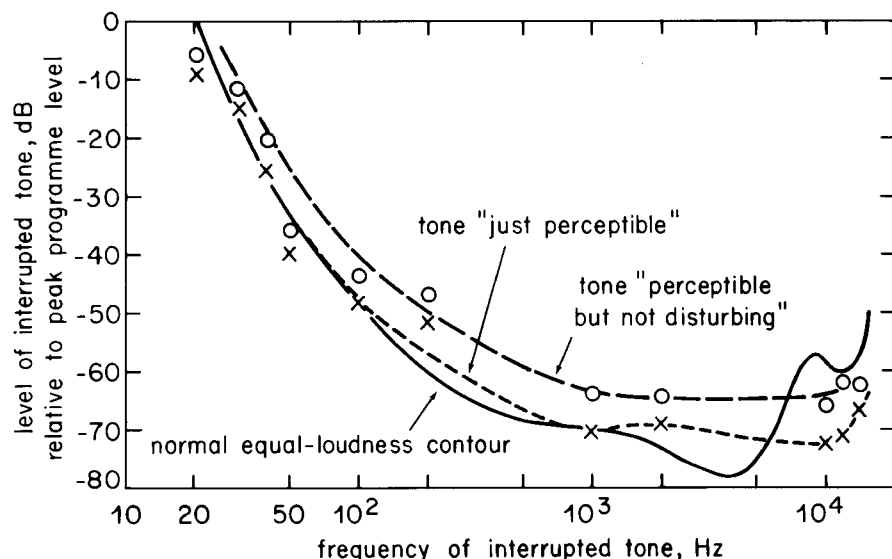


Fig. 3 - Perceptibility of interrupted tone: baseband-frequency tests

(at 400 Hz) when using frequency-modulation. In the same way as for the tests described in Section 2.2, the level of the speech programme was set to peak to 5 on the p.p.m. and the level of the interrupted tone was set so that, when attenuator 1 (see Fig. 1) was set to 0 dB, the presence of the tone caused the p.p.m. to read 6 in the absence of programme. Thus the setting of attenuator 1 indicated the level of the interrupted tone relative to peak programme level and, after modulating, the peak modulation corresponding to peak-programme-level-plus-interrupted-tone would not exceed 100% provided attenuator 1 was set to 19 dB or more.

For the tests, three receivers were used in turn. For amplitude-modulation a battery-portable receiver (Receiver 1), with its built-in loudspeaker, and an a.m./f.m. tuner (Receiver 2) feeding a loudspeaker type LS 5/5A, were used. For frequency-modulation a low-cost battery-portable receiver (Receiver 3) was used. The results using this small selection of receivers are regarded as sufficiently reliable for the present purpose but further tests using a larger selection may be necessary before the addition of data signals to broadcast programmes becomes a reality.

The tests were conducted in the same way as those described in Section 2.2, but with each listener in turn sitting only in the position symmetrically in front of the loudspeaker and about 1.5 m from it. Furthermore, each listener was asked to assess only the 'just perceptible' level of interrupted tone during the speech programme. Four experienced listeners took part in the tests involving the battery-portable receivers but only one in the tests involving the a.m./f.m. tuner. The judgements of this single listener, however, had previously been found to accord well with those of the other four. The results, shown in Fig. 4, are either the average for the four listeners or for the single listener, as appropriate. When using a.m., the highest frequency for the interrupted tone was 2 kHz but, when using f.m., tone at frequencies up to 14 kHz was used. At frequencies of 10 kHz and above, the results shown in Fig. 4 are those of only one listener, namely one of the two mentioned in Section 2.2, whose judgements were particularly stringent at those frequencies.

2.3.2. Tone programme

During the tests described in Section 2.3.1 it was

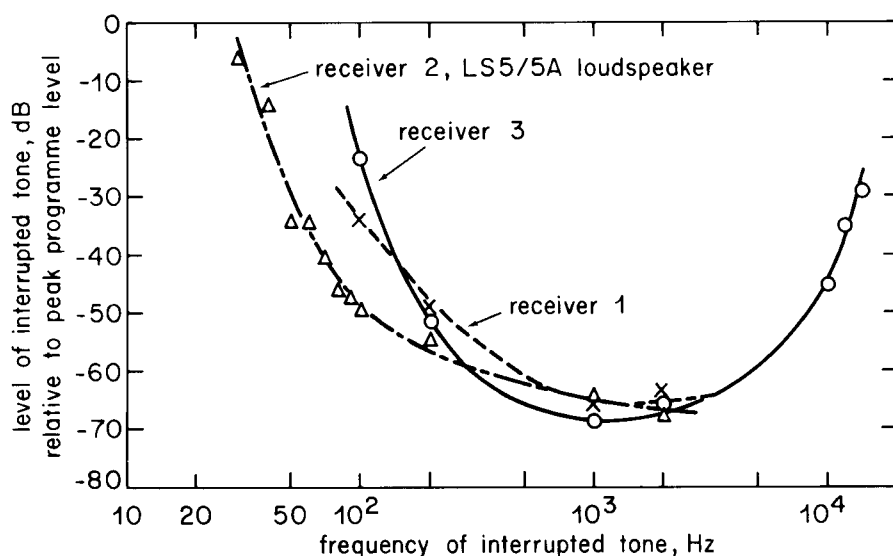


Fig. 4 - Perceptibility of interrupted tone: modulated-signal tests (interrupted tone 'just perceptible')

suggested that speech may not have been the most critical type of programme when assessing the perceptibility of the interrupted tone at low and very-low frequencies. As a result of modulation and demodulation (particularly a.m.) it was suggested that the interrupted tone may become intermodulated with the programme and hence cause a 'warbling' effect which may be more intrusive on programmes other than speech. It was considered that such an effect would be most pronounced on programmes involving long sustained chords and that such a programme could best be simulated by using steady tone.

Accordingly, a brief experiment was performed by two experienced listeners to assess the 'just-perceptible' levels of the low-frequency interrupted tone against a background of 400 Hz steady tone at 90% modulation depth. Three receivers were used, two of which had been used for the tests described in Section 2.3.1; the third receiver (Receiver 4) was a BBC high-quality medium-wave check-receiver. The average results for the two listeners are given in Table 2. They show not only that the frequency of the interrupted tone was of little consequence but also that, for two of the three receivers tested, the interrupted tone became noticeable only when the peak modulation depth of the steady tone and the interrupted tone together exceeded 100%. The performance of the third receiver (Receiver 2) was markedly inferior but subsequent tests showed that particular receiver to cause the rather high levels of harmonic distortion shown in Fig. 5. This could

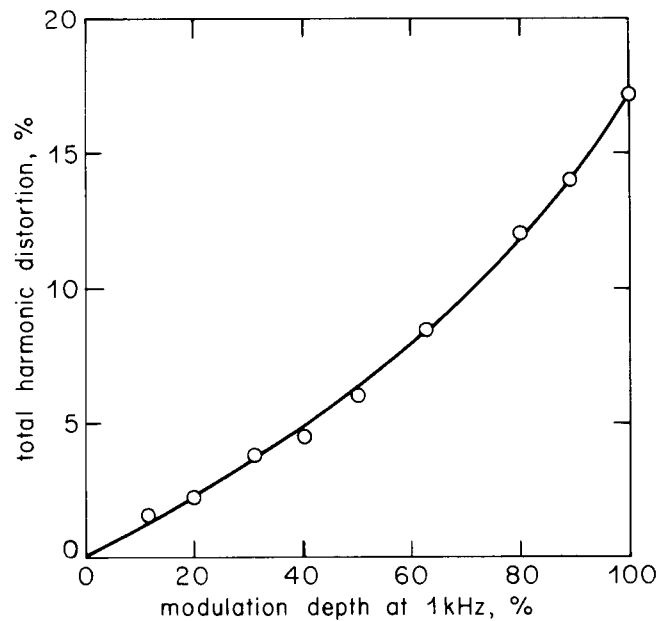


Fig. 5 - Harmonic distortion of Receiver 2 as a function of modulation depth

account for its inferior performance in this respect although it was noted that the distortion was of such a nature as not to cause marked impairment to normal programme reproduction.

TABLE 2

Perceptibility of interrupted tone in the presence of a steady tone

Frequency of interrupted tone (Hz)	Receiver No.	Type of loudspeaker	Level of interrupted tone relative to level of 400 Hz steady tone (dB) for 'just-perceptible' effect*
10 20 30 40	No. 2	LS5/5A	-25.5 -25 -25.5 -24.5
10 20 30 40	No. 3	LS5/5A	-19 -14.5 -14.5 -14
10 20 30 40	No. 3	Own in-built	-17 -17 -15.5 -16.5
10 20 30 40	No. 4	LS5/5A	-14 -15 -15 -17.5

* The level of the steady tone was set to correspond to 90% modulation depth. Thus the addition of the interrupted tone at relative levels greater than -19 dB would cause modulation depths greater than 100%.

3. Discussion of results

The variation of perceptible levels of interrupted tone as a function of frequency shown in Fig. 3 is in good agreement with that of the normal equal-loudness contour. These levels were established at baseband frequencies on the basis of perceptibility during a speech programme. This is likely to correspond to the most stringent case under practical modulation conditions over the great majority of the tone-frequency range but, at very low frequencies where the results of Fig. 3 would permit high levels of interrupted tone a lower limit may, on certain programmes, be determined by intermodulation between the tone and the programme. In this regime, the most critical programme is likely to comprise music involving long sustained chords. This lower limit would be determined by intermodulation within receivers and, so far, too few receivers have been tested to provide a reliable result. Nevertheless, the effect appears to be small insofar that, as shown in Table 2, it did not occur to all on two of the three receivers tested (i.e. it was not noticeable until the peak modulation depth exceeded 100%). The third receiver, on which it was noticeable, was found to have a rather poor distortion characteristic and hence may not be typical from this point of view. Furthermore, the effect was noticeable only on tone-modulation, simulating long sustained chords at 90% modulation depth, and was not noticeable on speech programme (see Fig. 4), even on this rather poor receiver.

It would therefore appear reasonable, if data signals are to be added to a.m. broadcasts, to add the data signals at levels (depending upon their frequency) according to Fig. 3 but with the restriction that the level of the data signals should not exceed -20 dB relative to peak programme level, even for low-frequency data. For f.m. broadcasts (both mono and stereo) a similar constraint may be necessary in order both to prevent over-deviation and as a precaution against possible similar intermodulation effects in f.m. receivers.

4. Conclusions

The work described in this Report has shown the dominant effect of adding switched tones, simulating data signals, on a broadcast programme to be their perceptibility during silent periods of the programme. From this point of view the values shown in Fig. 3 are appropriate when deciding upon the permissible levels of added tones. Intermodulation with the programme may dominate, however, if low-frequency signals are added at the levels shown in Fig. 3, particularly on programmes involving long sustained chords. For this reason it is recommended that, if signals are to be added to either a.m. or f.m. broadcast programme, their levels should not exceed the levels shown in Fig. 3, with the further restriction that no signal should exceed a level of -20 dB, relative to peak programme level, even for very low-frequency data. Since only a few receivers have so far been tested, however, this should perhaps be regarded as a tentative recommendation, to be finalised later if the proposals to add data signals to broadcast programmes are to be adopted. It would also be necessary, of course, to make the appropriate reduction in either peak modulation depth at a.m. transmitters or peak deviation at f.m. transmitters, due to the programme. This reduction would be small and could best be done by slightly reducing the maximum output level from the programme limiter at some point in the programme chain prior to the addition of the data signals.

5. References

1. HILL, P.C.J. Simultaneous subliminal signalling in conventional sound circuits: a feasibility study. BBC Research Department Report No. 1971/1.
2. ISO Recommendation R226, Appendix A, Table A-1, 1961.
3. ISO Recommendation R454, 1965.